MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2017/2018

EEN7026 – SEMICONDUCTOR PHYSICS AND MATERIALS

6 MARCH 2018
6.00 p.m. - 9.00 p.m.
(3 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 8 pages with 6 Questions only.
2. Attempt **All** questions. The distribution of the marks for each question is given.
3. Please write all your answers in the Answer Booklet provided.

Useful constants and coefficients:

Physical Constants

Boltzmann's constant (k)	1.3807×10^{-23} JK^{-1} 8.617×10^{-5} eVK^{-1}
Planck's constant (h)	6.626×10^{-34} Js
Thermal voltage@300K kT/e kT	0.0259 V 0.0259 eV
Electron mass in free space (m_e)	9.10939×10^{-31} kg
Electron charge (e)	1.60218×10^{-19} C
Effective density of states in the conduction band for Si (N_c)	2.8×10^{19} cm^{-3}
Effective density of states in the Valence band for Si (N_v)	1.2×10^{19} cm^{-3}
Permeability of free space (μ_0)	$4\pi\times10^{-7}$ Hm^{-1}
Permittivity of free space of free space (ε_0)	8.85×10^{-12} Fm^{-1}
Avogadro's number (N_A)	6.022×10^{23} atoms/mol

Question 1 [16 marks]

(a) Apply the time-independent Schrödinger wave equation $-\frac{\hbar^2}{2m}\frac{\partial^2\psi(x)}{\partial x^2}+V(x)\psi(x)=E\psi(x)$ to show that the energy of a free electron confined in one-dimensional infinite potential well is quantized and is given by $E=\frac{\hbar^2\pi^2n^2}{2mL^2}$, where n = 1, 2, 3, ….. and L is the width of the well. Assume that the potential in the well, $V(0<x<L)=0$.

[7 marks]

(b) At the first energy state, the electron normalized wave function in the infinite potential well of part (a) is given by $\psi(x)=\sqrt{\frac{2}{L}}\sin\left(\frac{\pi x}{L}\right)$.

(i) Sketch the probability distributions of the electron in this infinite potential well at first THREE allowed energy levels. [3 marks]

(ii) Explain what happen if the potential well is finite, that is V ≠ ∞. [1 marks]

(c) The Pauli Exclusion Principle states that no two electrons in a given atom may have the same set of quantum numbers n, l, m_l and m_s. Write down the electronic configurations of Si atom and the list of quantum numbers for all 14 electrons in a silicon atom.

[5 marks]

Continued….

Question 2 [18 marks]

(a) The periodic arrangement of atoms in a crystal is called lattice based on the geometrical concept. The distance, d, between two $(h\ k\ l)$ equivalent planes in a lattice can be calculated by $\frac{1}{d^2}=\frac{h^2}{a^2}+\frac{k^2}{b^2}+\frac{l^2}{c^2}$, where a, b, and c are the 3 primitive vectors and h, k, l, are the Miller indices.

(i) Draw the (100), (110), and (111) planes in a cubic lattice and determine the distance between equivalent planes in [100], [110], and [111] directions. [6 marks]

(ii) Sketch the <111> family of lattice directions in the cubic system. [3 marks]

(b) Figure Q2(b) shows the zinc blende structure where two species of atoms are placed alternatively in the diamond lattice structure. Draw the top view along any <100> direction of an extended diamond lattice to show that the diamond unit cell can be constructed by interpenetrating two Face-Centered Cubic (FCC) sublattices. [3 marks]

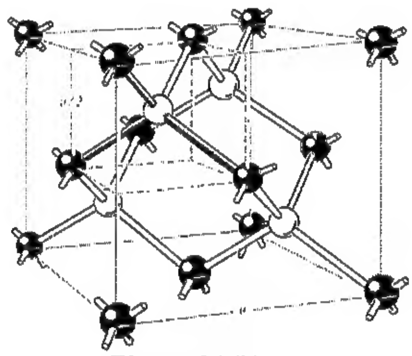

Figure Q2(b)

(c) The GaAs has the zinc blende crystal structure and the lattice parameter of GaAs, a = 0.565 nm and the atomic masses of Ga, and As are 69.73 g mol^{-1}, and 74.92 g mol^{-1}, respectively.

(i) What is the atomic concentration (atoms per unit volume) in GaAs crystal? [2 marks]

(ii) Calculate the density of GaAs. [4 marks]

Continued....

Question 3 [20 marks]

(a) Figure Q3(a) shows a direct bandgap semiconductor with the bottom of the conduction band occurs at the centre of Brillouin zone. The bandstructure near the bandedge (Γ) is isotropic and it can be represented by a simply relation of the form $E(k) = E_c + \frac{\hbar^2 k^2}{2m^*}$, where E_c is the conduction bandedge, k is the crystal momentum, $\hbar = h/2\pi$ and m^* is the effective mass.

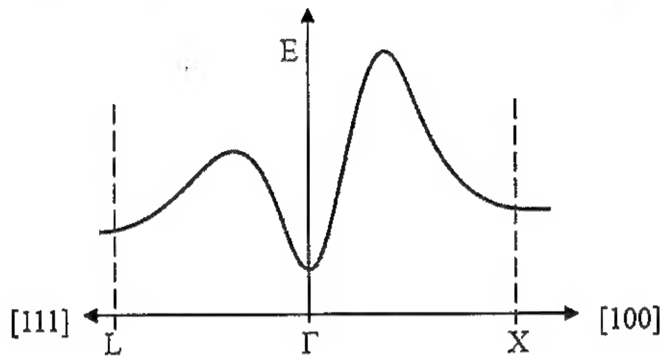

Figure Q3(a)

(i) Use the given relation to derive the velocity (v) and effective mass (m^*) of electron. [4 marks]

(ii) Sketch the effective mass and velocity of electron in this band as a function of crystal momentum (k) near the band edge. [2 marks]

(iii) Draw all the allowed k-values associated with a given energy near E_c in a 3D k-space plot. [3 marks]

(iv) If electrons were to transfer from the Γ-valley to the L-valley would their effective mass increase or decrease? Explain. [3 marks]

(b) Negative differential resistivity (NDR) is observed in N-doped semiconductors with conduction band similar to that of Figure Q3(a).

(i) What are conditions must be satisfied by the conduction band in order to exhibit the NDR? [3 marks]

(ii) Write down TWO semiconductors with NDR and briefly explain this phenomenon. [5 marks]

Continued….

Question 4 [18 marks]

(a) In N-doped semiconductors, the electrons from the donors will occupy higher energy states in particular go into the conduction band at a finite temperature.

(i) Explain why the fraction of the elections that are bound to the donors cannot be calculated by simply applying the Fermi-Dirac distribution function.

[4 marks]

(ii) Show that the probability of an electron being bound to the donor in an N-doped semiconductor is $f(E') = \left(1 + \frac{1}{2}\exp\left[\frac{E' - E_f}{kT}\right]\right)^{-1}$, where E_f is the Fermi energy level, k_B is the Boltzmann constant and T is the temperature. Write down your assumption and explain the factor of ½ in the equation.

[5 marks]

(b) In a heavily N-doped semiconductor, the large number of donor electrons closely packed to each other will introduce many body effects involve ionized impurity-electron interaction, electron-electron interaction, and electron-hole interaction that distort the density of quantum states in the conduction and valence bands. Briefly explain these THREE interactions.

[6 marks]

(c) In compound semiconductors like GaAs, the dopants can be "amphoteric". If Si atoms are injected as dopants and exclusively replace Ga atoms in the lattice, what is the resulted Si-doped GaAs material, n-type or p-type? Explain your answer.

[3 marks]

Continued....

Question 5 [14 marks]

(a) The Czochralski technique is widely employed in commercial growth of Si single crystals. Briefly the main advantages of this method.

[2 marks]

(b) The principal epitaxial growth methods are variants of the Physical Vapor Deposition (PVD) and Chemical Vapor Deposition CVD processes. Figure Q5(b) shows the process steps of Vapor Phase Epitaxy (VPE).

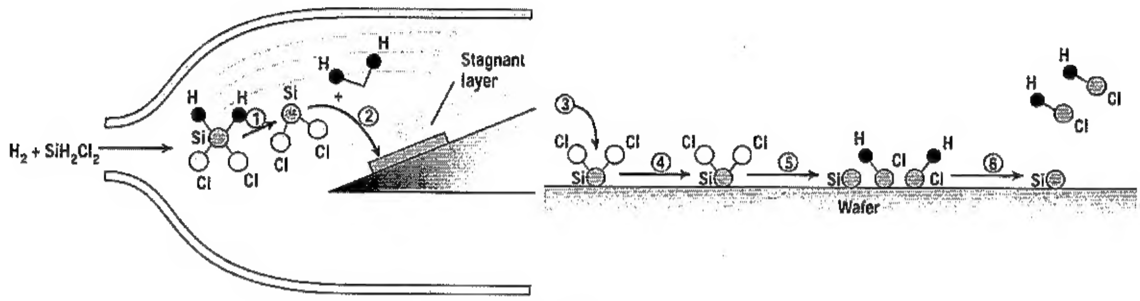

Figure Q5(b)

(i) Define epitaxy and briefly explain the advantages of epitaxy wafer against bulk wafer.

[4 marks]

(ii) Briefly describe the VPE process steps 1 to 6 as indicated in the Figure Q5(b).

[3 marks]

(iii) Explain what VPE cannot achieve as compare to the Molecular Beam Epitaxy (MBE) technique and briefly describe the MBE processes.

[5 marks]

Continued....

Question 6 [14 marks]

(a) In crystalline semiconductors, there are variety of point defects as shown in Figure Q6(a). Name the type of point defect A, B, C, and D in the Figure Q6(a).

[2 marks]

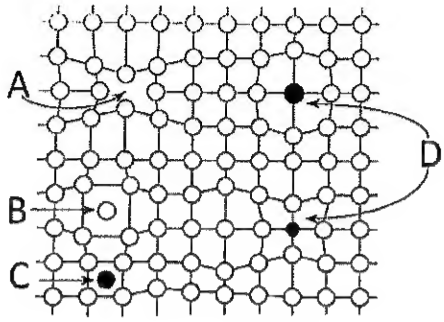

Figure Q6(a)

(b) Name the other THREE categories of defects in a crystal according to their geometry and give an example for each category.

[3 marks]

(c) Consider an equilibrium growth of a semiconductor at a temperature of 1000 K. The density of point defects is given by $N_d = K_d N_{sites} \exp\left(-\frac{\Delta E_d}{kT}\right)$, where N_{sites} the site density for the semiconductor is 2.5×10^{22} cm^{-3}, the energy needed to generate a point defect is $\Delta E_d = 2.0$ eV and K_d is the dimensionless constant equal to 5.5.

(i) What is the density of point defects in the semiconductor? [2 marks]

(ii) If a typical dislocation site due to the segregation of point defects initially formed at 1000 K has 500 missing atoms, calculate the density of dislocations in the semiconductor.

[2 marks]

(d) Gettering is an important process of removing device-degrading impurities from the active circuit regions of the Si wafer. This process can be performed during crystal growth or in subsequent wafer fabrication steps. Briefly explain the intrinsic gettering and its advantages as compare to extrinsic gettering.

[5 marks]

End of the paper